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(54) **Method for memorizing membership functions in a fuzzy logic processor.**

(57) Memorization method in an electronic controller operating with fuzzy logic procedures for membership functions (FA) of logical variables (M) defined in a so-called discourse universe (U) discretized at a finite number of points (m) which provide memorization of triangular or trapezoid membership functions (FA) by means of memory words comprising a first portion in which is contained a codification of the vertex of the membership function (FA) and a second portion containing a codification corresponding to the slope of at least one side of the membership function (FA) as well as a third portion containing a codification corresponding to the slope of at least one other side of the function.

	LEFT SLOPE	VERTEX	RIGHT SLOPE
FA_1	1111	00010100	0001
FA_2	0001	00111111	0001
FA_3	0001	01010111	0001
FA_4	0001	01110000	1111

FIG. - 5

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Field of the Application

The present invention relates to a memorization method for data on membership functions in a processor operating with fuzzy logic procedures.

Specifically the present invention relates to a memorization method in an electronic controller operating with fuzzy logic procedures for membership functions of logical variables defined in a so-called discourse universe discretized at a finite number of points and said method providing memorization of triangular or trapezoid membership functions FA.

Known art

Fuzzy logic is now confirmed as a technique capable of supplying solutions for a broad range of control problems for which the conventional techniques, e.g. those based on Boolean logic, have proven unsuited for providing acceptable performance at acceptable cost.

Fuzzy logic operates on a linguistic description of reality using a particular class of variables termed linguistic variables. The value of said variables consists e.g. of words or phrases of a natural or artificial language. Basically, to each variable is assigned a corresponding semantic meaning of the words or phrases which are used in modelling of a given problem.

In addition, with each variable can be syntactically combined a group of values dependent on it and which can take on different meanings depending on the context in which they are employed. These values are obtained starting from a primary term representing the variable, from its contrary, and from a series of so-called modifiers of the primary term, e.g. as described in European patent application no. 92830095.3.

Each value assigned to a linguistic variable is represented also by a so-called fuzzy set, i.e. a possibilistic distribution function which links each value of the variable in the corresponding definition domain, known also as discourse universe.

The functions which identify a fuzzy set in the discourse universe of a variable are termed membership functions f(m). For example, a value f(m) = 0 indicates non-membership of the point m in the fuzzy set identified by the function f whereas value f(m) = 1 indicates the certainty of the membership of m in the fuzzy set. The entirety of all the fuzzy sets of a linguistic variable is termed 'term set'.

Among the membership function can be performed appropriate logical operations, termed inference, which permit description of the behavior of a system with the variation of the input parameters. These operations are performed by means of fuzzy rules which have generally a syntax of the type:

IF X IS A, THEN Y IS B

where X is the input value, A and B are membership functions which represent knowledge of the system, and Y is the output value.

The part of the rule which precedes the term THEN is termed 'left' or antecedent, while that which follows it is termed 'right' or consequent part of the inference rule.

The electronic data processing instruments which allow performance of the operations on the membership functions must be provided with a particular architecture expressly dedicated to the entirety of inference operations which constitute the fuzzy logic computational model.

To obtain a satisfactory result it is however of basic importance that the membership functions of the fuzzy sets be sufficiently and correctly defined in the control device. Indeed, the more said definition reflects the semantics of the fuzzy concept the more the incidence of a term in a rule will be correct and consequently also the value output by the electronic controller operating with fuzzy procedures will better reflect reality.

At present, the definition or memorization in an electronic controller based on the fuzzy logic of the membership functions which identify the fuzzy sets represents one of the major constraints on the development of new fuzzy logic applications, thus limiting the theoretical potentials of this methodology.

Indeed, if for the implementation on hardware of the membership functions it is desired that said functions respect the semantics of the fuzzy concept so as to obtain a correct incidence of a term in a rule, one is forced to use considerable space in the memory. This makes fuzzy logic advantageous only for those applications where the term set of the linguistic variable consists of a small number of membership functions.

A first solution to this shortcoming consists of memorizing only some considerable points of a membership function and in particular those in which the function changes inclination, thus obtaining a drastic reduction in memory size. But since the task of performing AND-function between said points to proceed with the actual fuzzy computation is assigned to the fuzzy device, there is a considerable increase in computation because of calculation of the intermediate points. In addition, the devices based on this method are inflexible because they operate with a limited number of forms of predetermined membership functions.

Devices which use this type of memorization for the membership functions are machines called FP-3000 of the OMRON Corporation, or the NLX-230 of the Neural Logix Corporation. These devices operate with digital technology representing the membership functions in analytical form.

Digital technology allows also representation of the membership functions in vectorial form while discretizing the discourse universe at a finite number of points and memorizing the corresponding degree of membership of the membership functions at these points.

Among the advantages of this technology there is surely good definition of the membership functions in the control device and the extreme computational simplicity with which can be performed the computations, i.e. the fuzzy inferences.

With this high calculation speed is associated however a considerable spending of memory due to the fact that for each membership function there must be memorized the value it has at all points of the discourse universe.

The data for a membership function are stored in a memory word. In known devices the memory area occupied is thus negatively influenced by the number of data necessary for defining these membership functions.

In many cases it is sufficient to memorize triangular membership functions and in general not symmetrical or at most of trapezoid form so as to reduce the number of data necessary for their memorization.

Processors which use this type of triangular function are known. For example the NeuraLogic fuzzy controller NLX230 memorizes for each membership function antecedent to the position of the vertex (using eight bits) and the value of the semi-base of the triangle which represents the membership function (using another five bits, i.e. a range of thirty-two values (2^5) of which the greatest represents the height of the vertex).

With this controller there can however be used only symmetrical membership functions.

The NeuraLogic solution also exhibits problems for slopes other than 45°. Indeed, it is not possible to implement triangular functions with slopes less than 45° which necessitate semi-bases of sizes greater than those which can be represented by means of five bits. In addition, for semi-bases less than this value the NLX230 controller performs a 'cut' of the membership function as shown in figures 1 and 2 where FA indicates a membership function.

Finally, with this type of memorization it is not possible to consider a number of truth levels different from that which can be represented with five bits.

The technical problem underlying the present invention is to provide a method for digital memorization of the membership functions FA which would allow minimizing the size of the memory required for implementation on hardware of said functions.

This would allow keeping a high computation speed and optimization of memorization of the membership functions FA while overcoming the shortcomings which still limit the known solutions.

Summary of the Invention

The solution idea underlying the present invention is that of memorizing triangular membership functions FA by means of the value of the vertex and of the slopes of the triangle sides.

On the basis of this solution idea said technical problem is solved by a memorization method for membership functions FA defined by the characterizing part of the annexed claims.

The characteristics and advantages of the method in accordance with the present invention are set forth in the description of an embodiment thereof given below by way of example and not of limitation with reference to the annexed drawings.

Brief Description of the Drawings

In the drawings:

- FIG 1 shows schematically a possible membership function in fuzzy architecture provided in accordance with the known art,
- FIG 2 shows a deformation of a membership function in a fuzzy architecture provided in accordance with the known art,
- FIG 3 shows a possible term set of membership functions FA memorizable by the method in accordance with the present invention,
- FIG 4 shows the organization of a memory device in accordance with the present invention for memorization of membership functions FA of the type of those of FIG 3,
- FIG 5 shows the structure of a memory word which describes in accordance with the present invention one of the membership functions FA of FIG 3,
- FIG 6 shows a translation in binary code in accordance with the present invention of some membership functions FA of FIG 3, and
- FIG 7 shows some types of membership functions FA memorizable by the method in accordance with the present invention.

Detailed Description

With reference to FIG 3 the term set of a linguistic or logical variable M is represented by means of a vectorial system where along the axis of the abscissas is defined the so-called discourse universe U while along the axis of the ordinates is defined the degree of truth or membership G.

In this specific case the discourse universe U and the degree of membership G are discretized in

two hundred fifty-six points m and sixteen levels or values L. The term set consists in our example of four membership functions FA_i which identify in the discourse universe U as many fuzzy sets (i is the index of each membership functions).

In FIG 3 the membership functions FA are numbered with the indices i from one to four increasing from left to right. The term set represented in FIG 3 could be e.g. a display in vectorial form of the variable 'temperature'.

A linguistic variable of this type lends itself to a mathematical modelling based on fuzzy logic.

With an electronic control device provided for operation in fuzzy procedure and described e.g. in European patent application no. 92830095.3 it is possible to put into effect a fuzzy logic modelling of linguistic variables of the type represented by the term set of FIG 3.

With reference to FIG 4, 1 indicates schematically as a whole an electronic memory device provided in accordance with the present invention. For the sake of simplicity of exposition let us assume that said device is the antecedent data memory (ADM), i.e. the data of the functions located in the antecedent part of the inference rules.

Said antecedent data memory ADM is connected to the microprocessor μ and is divided in multiple memories 2 each having dimensions equal to:

$$\text{nfa (words)} * \text{nbw (bits)}$$

where:

- nfa is the maximum number of membership functions FA which make up the term set of the input variables, and
- nbw is the number of bits of each word making up each memory 2.

The antecedent data memory ADM will thus have an overall size given by:

$$\text{nfa (words)} * \text{n (memories)}$$

where n is the number of inputs of the fuzzy processor.

Since each word must contain the data for a membership function FA its length will depend on the methodology used to memorize it.

In the method in accordance with the present invention each membership function FA has a triangular form or at best trapezoidal at the edges of the discourse universe U. It is possible to define completely these functions by means of the coordinates of their vertex and of the value of the left and right slopes of the vertex of their graph.

In the method in accordance with the present invention a memory word has the structure of FIG 5 where a first portion comprises nbp bits which memorize a logical or digital value corresponding to the slope of the left side and a second and adjacent portion comprises nbv bits which memorize the position of the vertex in the discourse universe U (number of bits equal to the number of levels which make up the discourse universe U) and a third and terminal portion comprises nbp bits which memorize the value of the slope of the right side.

It is seen thus that the size of a memory word is equal the:

$$nbw = (2 * nbp) + nbv$$

Advantageously in accordance with the present invention the value of the nbp bits which memorize the right and left slopes of the membership function FA depend on the value of a flag which we shall call 'inclination_type' which is in turn memorized in the microprocessor μ.

If the value of the flag is zero, nbp bits in the memory word indicate the number of vertical levels by which is decreased the membership function FA at each horizontal unitary increase starting from the coordinate of the vertex.

For example, a binary value of 3 indicates that the membership function FA at the point of the discourse universe U which follows the coordinate of the vertex has a height three levels less than that of the vertex.

Vice versa, if the value of the flag is one, nbp bits of the memory word indicate after how many points of the discourse universe U the ordinate of the membership function FA is decreased by one unit in relation to the height of the vertex.

The memorization method for membership functions FA in accordance with the present invention for a processor operating with fuzzy logic operates on the basis of two flags termed 'left inclination_type' and 'right inclination_type'. It is possible in this manner to use both of the above mentioned definitions in the same process obtaining a large number of different slopes both in the immediate proximity of the 'vertex' and in the rest of the discourse universe U.

In total there can be described up to:

$$(2 * (2^{nbp}) - 2)^2$$

different types of membership function FA located at any point of the discourse universe U.

To better explain the mechanism underlying the memorization of membership functions FA in accordance with the present invention let us consider for example a case with nbp = 4. In this manner the slope can take on the values from 0 to 15: the value 0 indicates a straight vertical line while the value 15 indicates a straight horizontal

line.

The values from 1 to 14 combined with the 'left inclination_type' and 'right inclination_type' flags characterize the various inclinations of the triangle so that there can be described 14 + 14 = 28 different inclinations.

There are thus obtained at least thirty different types of slopes for the left part and the same number for the right part. In total the user can choose among 900 different membership functions FA.

FIG 7 shows some of the membership functions FA which the user can describe.

Assuming that the discourse universe U is made up of 256 points (from 0 to 255), i.e. it can be described by means of 8 bits (2^8 = 256) to describe a single membership function FA a word made up of 16 bits divided as follows is sufficient:

- 8 bits to indicate the position of the vertex of the membership function FA since the vertex can take on any value in the discourse universe U,
- 4 bits to indicate the slope of the LEFT part of the membership function FA, and
- 4 bits to indicate the slope of the RIGHT part of the membership function FA.

The structure of the memory word is shown in FIG 5. For convenience the 4 bits for the left slope are placed to the left of the vertex in the word while the 4 bits for the right slope are place to the right of the vertex in the word.

In the term set of FIG 3 are shown the values of the positions of the vertices and the transformations in binary code of the slopes of the sides. In the case of trapezoid membership functions FA the vertex indicates the point of the discourse universe U at which the membership function FA changes slope.

The corresponding memory words are shown in the table of FIG 6.

This memorization method for the membership functions FA permits implementation of a fuzzy architecture using extremely small memory devices. The reduction factor compared with the vectorial representation can be clarified by the following examples.

Let us consider initially a fuzzy architecture with 8 inputs and 8 membership functions FA while the discourse universe U is divided in 128 ranges and the maximum value of the heights of the vertices is 15.

Under these conditions the antecedent memory passes from the vectorial representation:

4*(128*64) bits (4,096 Kbyts)

to the representation in accordance with the present invention :

8*(8*13) bits (0,104 Kbytes)

There is obtained in this first case a reduction factor equal to:

red. % = 4,096/0,104 = 40 % appx

If there is considered then the case of a fuzzy architecture with still 8 inputs and 8 membership functions FA but with a discourse universe U divided in 256 ranges and a maximum value of the heights of the vertices equal to 63 there is found for the vectorial representation:

4*(256*96) bits (12,288 Kbytes)

and for the representation in accordance with the present invention :

8*(8*16) bits (0,128 Kbytes)

i.e. a reduction factor equal to:

red. % = 12,288/0,128 = 96 %

Advantageously in accordance with the present invention it is possible to modify the height of the vertex without having to change the data memorized in the antecedent data memory ADM.

This could be important in those cases where it is necessary to obtain high precision of the fuzzy controller, a precision linked to a high number of truth levels L, rather than a high resolution m of the discourse universe U.

In addition it is possible to increase the number of input variables, in the examples considered again equal to 8 since this value is sufficient in the majority of common commercial applications, by merely adding a memory of (nfa * nbw) bits for each additional input.

It is also possible to increase the number of membership functions FA of the term set considered by adding a word for each additional membership function FA or extending the discourse universe U while increasing the dimensions of the words used.

Finally it is possible to increase the internal parallelism for calculation of the coordinates of the vertices so as to obtain very fast timing, employing extremely small memory devices.

From a thorough examination it can be observed that with the memory organization method in accordance with the present invention the requirements of a large number of fuzzy logic applications are satisfied.

Although binding the user to the use of triangular or trapezoid membership functions FA the result

is modelling adequate for the majority of applications.

Among the principal advantages secured by the memory organization method in accordance with the present invention it also appears important to note the fact that the antecedent memory area is increased in a negligible manner with variation of the number of inputs, of the number of membership functions FA and of the degree of discretization of the discourse universe U.

Furthermore the degree of vertical discretization does not affect the dimensions of the memory and computation of the heights of the membership functions FA at the points m of the discourse universe U performed by a combinatory network is not slowed.

Lastly, there is a clear saving of memory area by applying the memorization method in accordance with the present invention.

Claims

1. Memorization method in an electronic controller operating with fuzzy logic procedures of membership functions (FA) of logical variables (M) defined in a so-called discourse universe (U) discretized at a finite number of points (m) and said method providing the memorization of triangular or trapezoid membership functions (FA) and characterized in that said membership functions (FA) are memorized by means of memory words comprising a first portion in which is contained a codification of the vertex of the membership function (FA) and a second portion containing a codification corresponding to the slope of at least one side of the membership function (FA).

2. Method in accordance with Claim 1 characterized in that said memory word comprises a third portion containing a codification corresponding to the slope of at least one other side of the function.

3. Method in accordance with Claims 1 and 2 characterized in that said at least one side and said at least one other side of the membership function (FA) are half-lines with origin in the vertex of the membership function (FA) and opposed thereto.

4. Method in accordance with Claim 1 characterized in that the first portion of the memory word comprises a number of bits nbv equal to those necessary to describe the discourse universe (U).

5. Method in accordance with Claim 1 characterized in that the second portion of the memory word comprises a number of bits nbp equal to those necessary to describe the slope of one side of a membership function (FA).

6. Method in accordance with Claim 1 characterized in that the meaning of the nbp bits which represent the slope depends on the value of a flag.

7. Method in accordance with Claim 6 characterized in that when the flag is set at logical value '0' the binary content of the nbp bits of the corresponding slope represents the number of vertical levels by which the membership function (FA) is decreased for each horizontal unitary shift in the discourse universe (U).

8. Method in accordance with Claim 6 characterized in that when the flag is set at logic value '1' the binary content of the nbp bits of the corresponding slope indicates after how many points (m) of the discourse universe (U) in relation to the coordinate of the vertex the height of the membership function (FA) is decreased by one unit.

9. Method in accordance with the above claims characterized in that the membership functions (FA) are stored in memory words of dimensions given by:

$$nbw = (2 \cdot nbp) + nbv$$

where:
- nbw is the number of bits contained in a memory word,
- nbp is the number of bits necessary for memorizing the slope of the membership function (FA) and
- nbv is the number of bits necessary for memorizing the vertex of the membership function (FA).

10. Method in accordance with claim 9 characterized in that the dimensions of the memory which contains the membership functions (FA) are equal for each input variable to:

$$nfa\ (words) \cdot nbw\ (bits)$$

where:
- nfa is the maximum number of membership functions (FA) making up the term set of the fuzzy input variables.

11. Method in accordance with Claim 9 characterized in that the coordinate of the vertex contained in the first portion of the memory word can be modified depending on requirements.

12. Method in accordance with Claim 9 characterized in that for each additional input variable the size of the memory is increased by (nfa * nbw) bits.

13. Method in accordance with Claim 9 characterized in that for each additional membership function (FA) added to a term set the size of the memory is increased by one word.

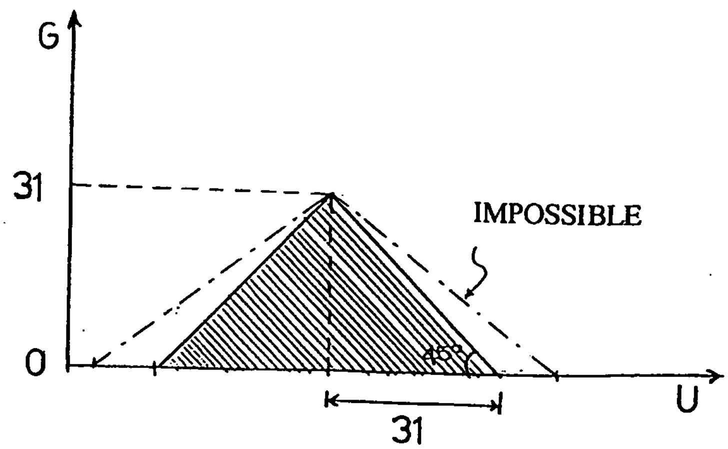

FIG. - 1
PRIOR ART

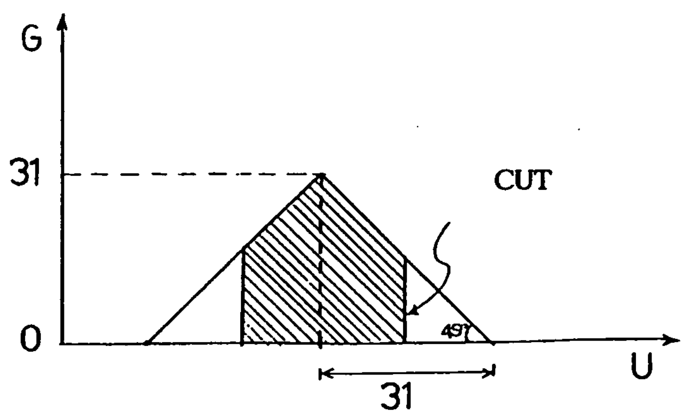

FIG. - 2
PRIOR ART

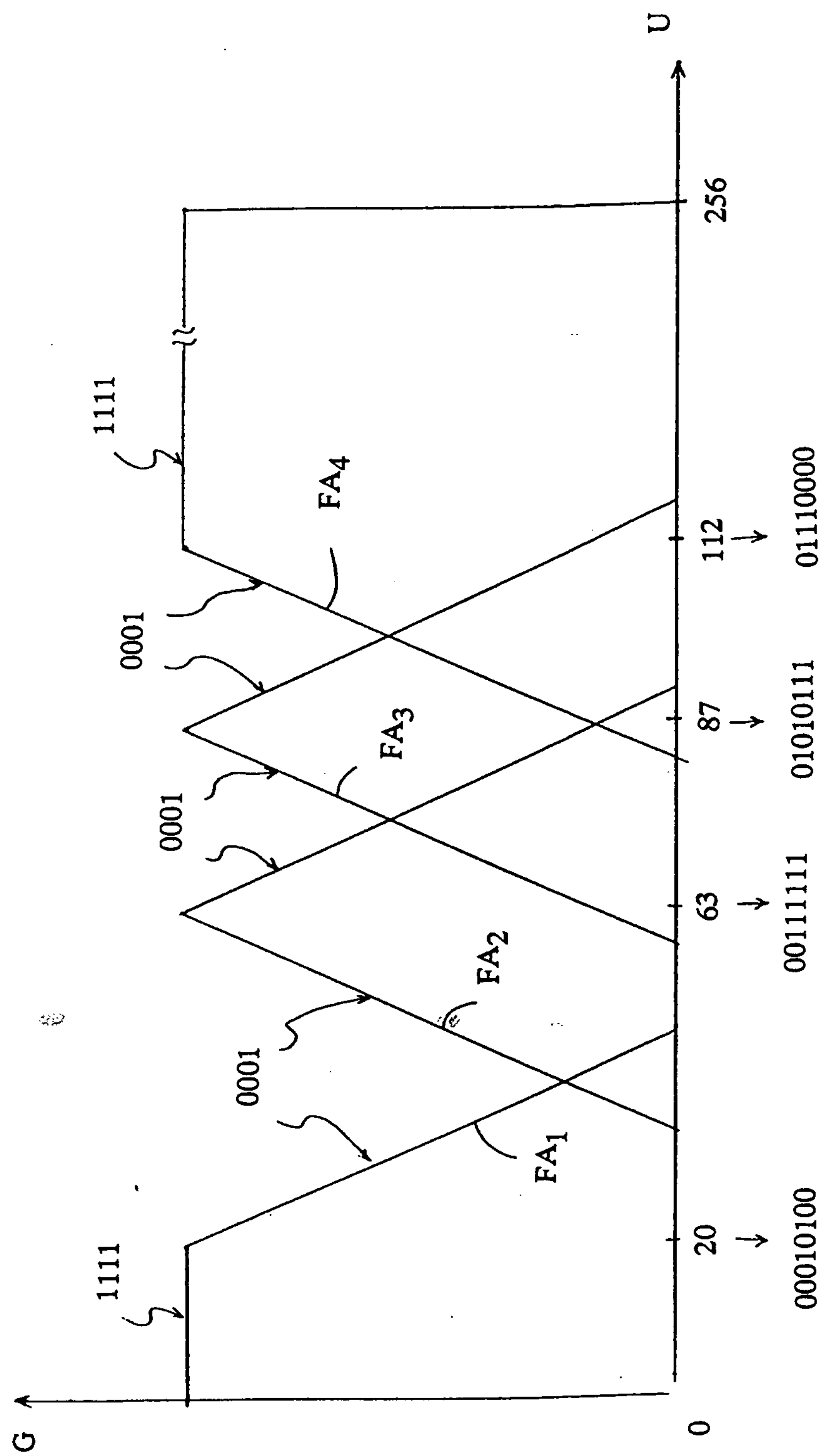
U
G
0
20
63
87
112
256
00010100
00111111
01010111
01110000
1111
1111
0001
0001
0001
FA1
FA2
FA3
FA4

FIG. - 3

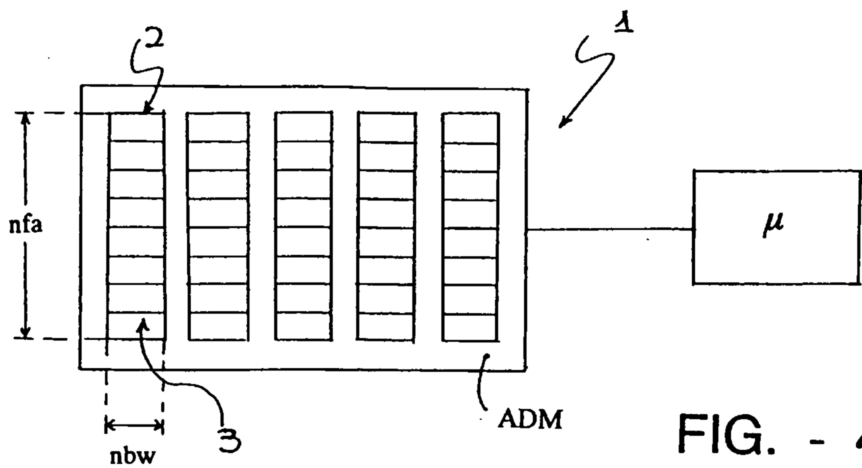

FIG. - 4

	LEFT SLOPE	VERTEX	RIGHT SLOPE
FA_1	1111	00010100	0001
FA_2	0001	00111111	0001
FA_3	0001	01010111	0001
FA_4	0001	01110000	1111

FIG. - 5

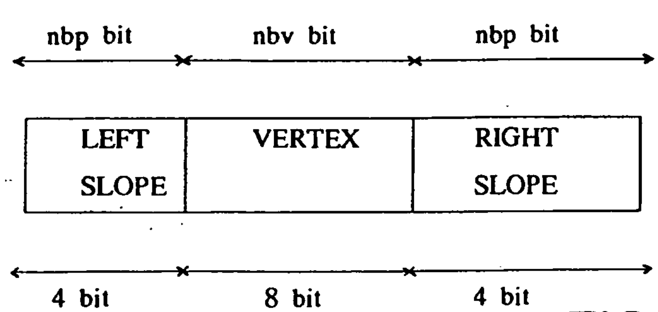

FIG. - 6

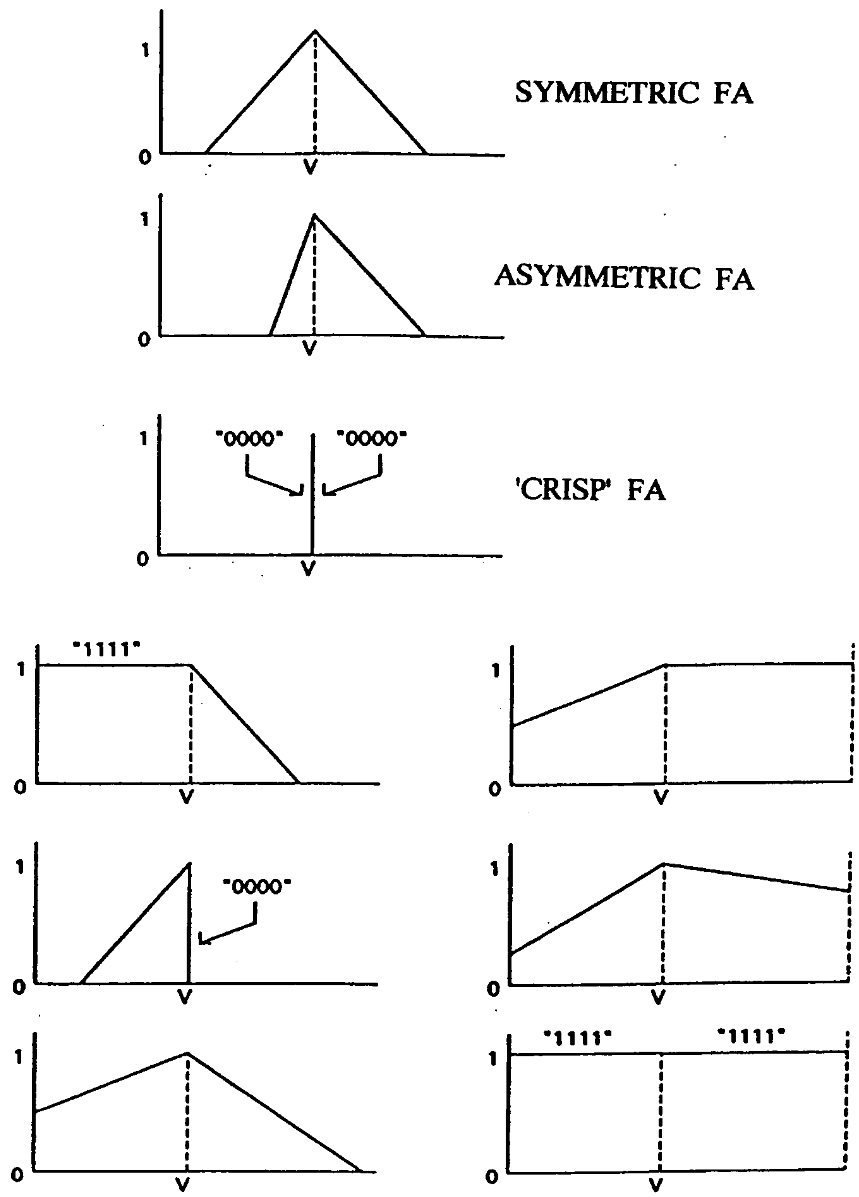
SYMMETRIC FA
ASYMMETRIC FA
"0000"
"0000"
'CRISP' FA
"1111"
"0000"
"1111"
"1111"
1
0
V

FIG. - 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 83 0158

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	DE-A-39 36 503 (OLYMPUS OPTICAL CO.) * page 9, line 43 - line 60; figures 24,25 *	1-5,9-13 6-8	G06F7/60
X	US-A-5 179 629 (NAKAMURA) * abstract * * column 3, line 38 - line 68; figure 4 * * column 6, line 27 - line 37; figure 9 *	1	
Y	IBM TECHNICAL DISCLOSURE BULLETIN., vol.20, no.12, May 1978, NEW YORK US pages 5370 - 5371 'Bresenham Data Compression Technique' * the whole document *	6-8	
A	EP-A-0 574 714 (MOTOROLA) * claims 1,2; figure 2 *	1,6-8	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G06F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	2 September 1994	Cohen, B

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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